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# Automatic Guidance System Development Using Low Cost Ranging Devices

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# Automatic Guidance System Development Using Low Cost Ranging Devices

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***Abstract***. *Autonomous guidance of agricultural vehicles for various field operations serves to increase productivity. Low cost infra-red ranging devices were used in this study to estimate the guidance directrix (offset distance (d) and heading error angle (Ø)). Two kinds of tracks were used for evaluating the performance of the infra-red sensors, one track was made of a cardboard in the laboratory and the other track was made of wheat crop in the field. The cardboard track consisted of straight parallel and non parallel edges whereas the wheat crop track had a series of different edges including few curves. From the results it was concluded that the sensor consistently detected the profile of the tracks with good repeatability .Errors of 6% were observed in detecting the straight edges and errors 6.6% and 13% were obtained in detecting two different angled surfaces. The reasons for the errors were detected and explained briefly in the paper.*

## Introduction

Precision agriculture, in today's competitive agriculture is widely implemented, where agricultural producers are increasing crop yields and minimizing the costs of field operations. With the advent of new technologies, site-specific and efficient management of field operations are made possible in most of the farms across the world. Autonomous operations of field machines have been given a lot of focus to save time and increase the accuracy of field operations. Specifically, automated guidance of agricultural vehicles is what makes the agricultural vehicles autonomous. Current technologies pertaining to automated guidance are found to be expensive and unattractive for a typical farmer to incorporate it in day to day field work. Most of the automated guidance mechanisms use either global position systems (GPS) or expensive machine vision techniques to guide the agricultural machine. These technologies are found to involve complex computation and image processing techniques to generate the guiding parameters for automated navigation which adds to the already existing high cost. The current project is focused on developing a low cost automated guidance methodology for row-crop applications which can be applied to the existing agricultural vehicles. The successful development of this methodology will relieve machine operators from the arduous task of machine guidance in standing row crops.

Automated guidance can be broadly classified into two categories; satellite based (GPS) guidance and non satellite based guidance (in situ sensor that includes lasers, cameras for 2D image acquisition, NIR reflectance sensor, etc.). GPS and machine vision systems act as position and heading sensors which provide information about navigation and relative positioning between the vehicle and the guidance directrix. Reid and Searcy, (1987) worked with special purpose cameras which have been developed by combining standard sensors with optical filters. A four antenna carrier-phase GPS system for guiding a John Deere 1800 tractor on prescribed straight row courses with headland turns was developed by O'Connor et al. (1995). Several image processing techniques were applied to the response obtained from vision based sensors for automated guidance (Gerrish and Surbrook, 1984; and Gerrish and Stockman, 1985). Machine vision was used to sense the edge of the uncut crop (Ollis and Stentz, 1996) and guide a New Holland windrower automatically. Thus, the ultimate goal of machine vision systems is to output the heading angle and the offset of the crop rows relative to the vehicle. Hence, the guidance parameters obtained from GPS and machine vision systems are used to provide control signals to the steering controller which adjusts the steering angle of the vehicle.

In order to follow a guidance line, two parameters have to be known: the distance from the datum line and the heading error angle (Tillet. 1991). Displacement can be measured at two points on the vehicle and then the heading angle can be calculated. This procedure was adopted as a starting point for this research study.

## Objectives

The main objectives of this research study are

- To evaluate the suitability of using low cost infrared sensors for automatic guidance.
- To test the infrared sensor arrangement in laboratory conditions and field conditions (straight and curved standing crop rows).
- To determine the guidance directrix (heading error angle (Ø), distance from the datum (*d*)) of the autonomous vehicle.

## Materials and Methods

### *Sensor used*

A low cost ($10) Infra-red sensor (GP2Y0A02YK) with sensing range of 20 cm to 150 cm manufactured by SHARP was evaluated to test the viability of using it for generating guidance parameters. Initially the sensor was calibrated with sensor placed at distances 5, 10, 20, 37.5(25% of $d_{max}$), and 112.5(75% of $d_{max}$) and 150cm away from the target. Five replications were made at each distance and the average voltage output from the sensor was plotted against the known distance to obtain a calibration curve. Figure 1 depicts the calibration curve of the sensor which conforms to the specifications provided by the manufacturer

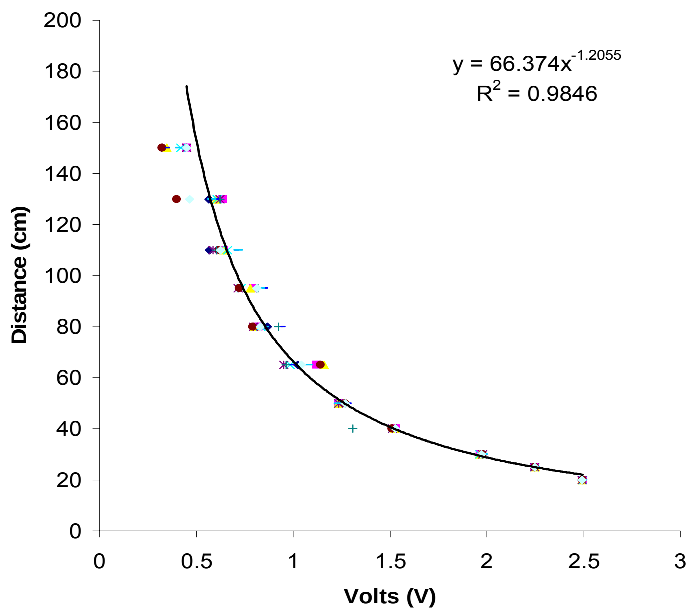



**Figure 1. Calibration curve of the sensor**

### *Sensor Configuration*

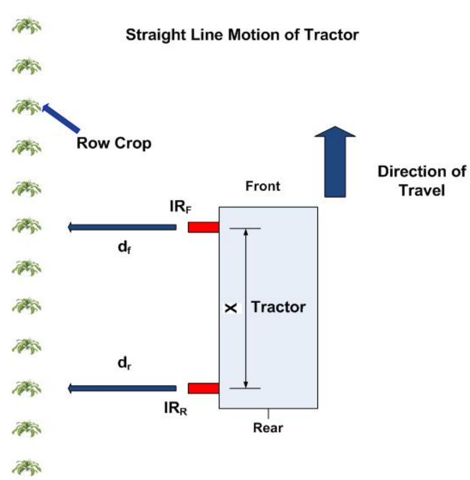



**Figure 2. Infra-red sensor configuration on the test vehicle**

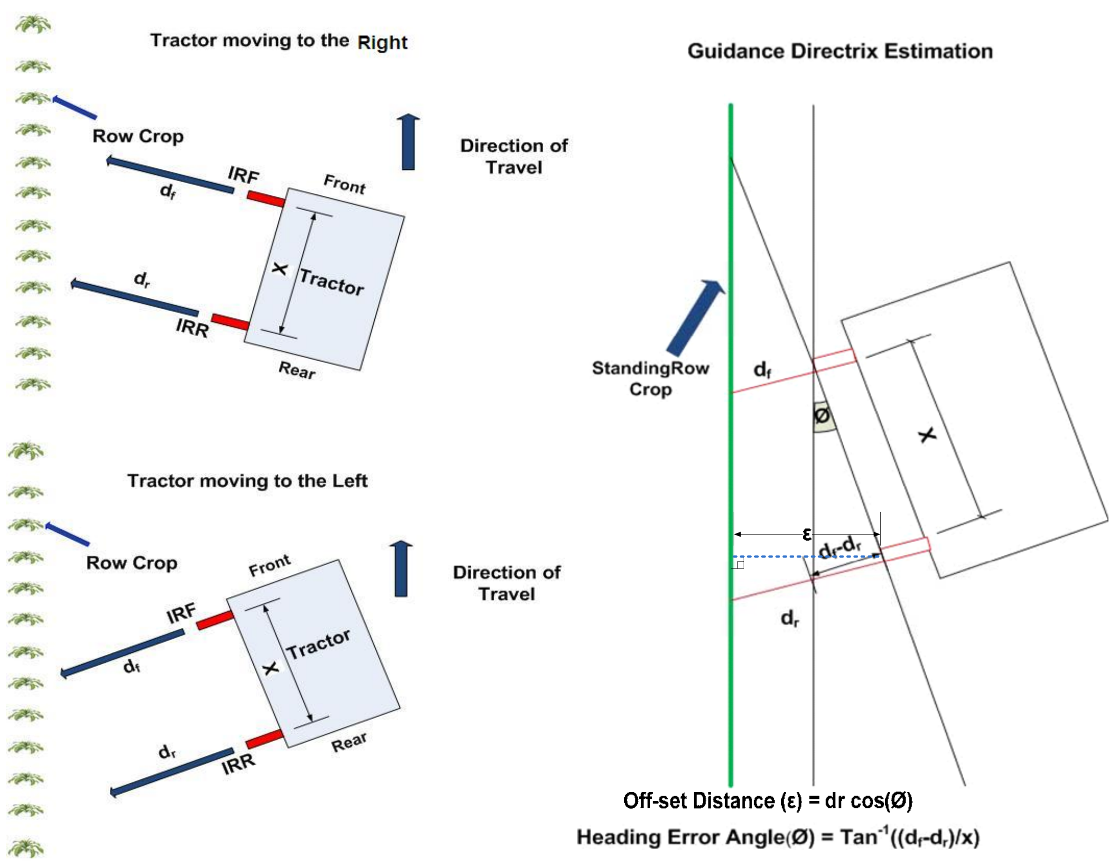



**Figure 3. Vehicle geometry when the sensors are moving non-parallel to the standing crop**

## *Guidance parameter estimation method*

Two sensors IRF and IRR are mounted (figure 2) on one side of the tractor at distance X = 30.48cm (12 in) apart. The two sensors give the distance outputs $d_f$ and $d_r$ respectively whenever the sensor senses a crop row. The distances given by two sensors are approximately equal when the tractor is traveling parallel to the crop. When the tractor is travelling non - parallel (figure 3) to the crop the distance outputs are not equal and the difference of the distance outputs from the two sensors can be used to determine the heading error angle (Ø) using equation 1.

$$\text{Tan}(\text{Ø}) = (d_f - d_r)/X \qquad (1)$$

Where,

Ø = Heading error angle (deg)

$d_f$ = Distance output (cm) given by sensor in front (IRF)

$d_r$ = Distance output (cm) given by sensor in rear of the tractor (IRR)

The numerator of equation (1) becomes negative when the tractor is moving to the left as the distance output given by IRF is less than distance output given by IRR (figure 3). Thus if we consider range of heading error angle (Ø) as [-π/2, π/2] then the Ø is negative when the tractor is turning to the left with respect to the crop and it is positive when the tractor is turning to the right with respect to the crop . The offset distances from the datum (row crop) can be estimated using equation 2 and 3.

$$\varepsilon_f = d_f \cos(\varnothing) \tag{2}$$

$$\varepsilon_r = d_r \cos(\varnothing) \tag{3}$$

Where,

$\varepsilon_f$ = offset distance (cm) given by sensor in front (IRF)

$\varepsilon_r$ = offset distance (cm) given by sensor in rear (IRR)

## Testing and Data collection

Testing of the infra-red sensors was done both in the lab and the field conditions.

### *Lab testing*

The test rig consisted of a simple garage opener which moved the two infrared sensors at a constant speed in a straight line. The target was made with a card board which had parallel and non –parallel profiles. The lab set up can be seen in figure 4. The distance output data from the two sensors $d_f$ , $d_r$ were collected at a constant speed 0.6 km/hr. A 12-bit A/D data acquisition device was used to digitize and store the data. Distance output data from the infra-red sensors was collected at 1000 Hz for all the test runs

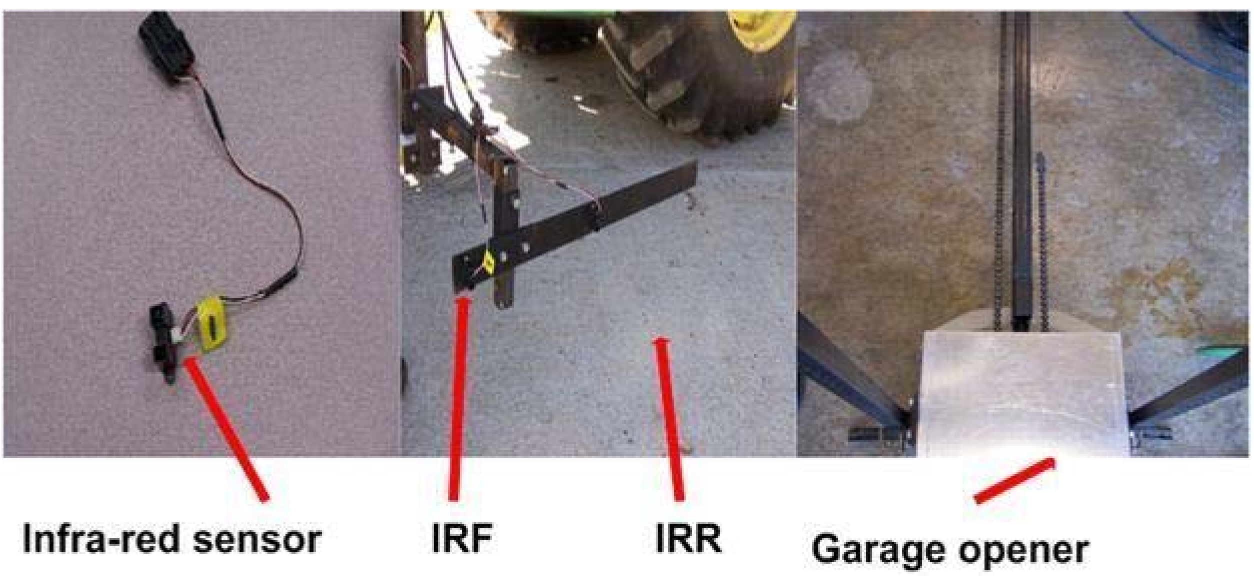



**Figure 4. Sensor configuration (lab setup)**

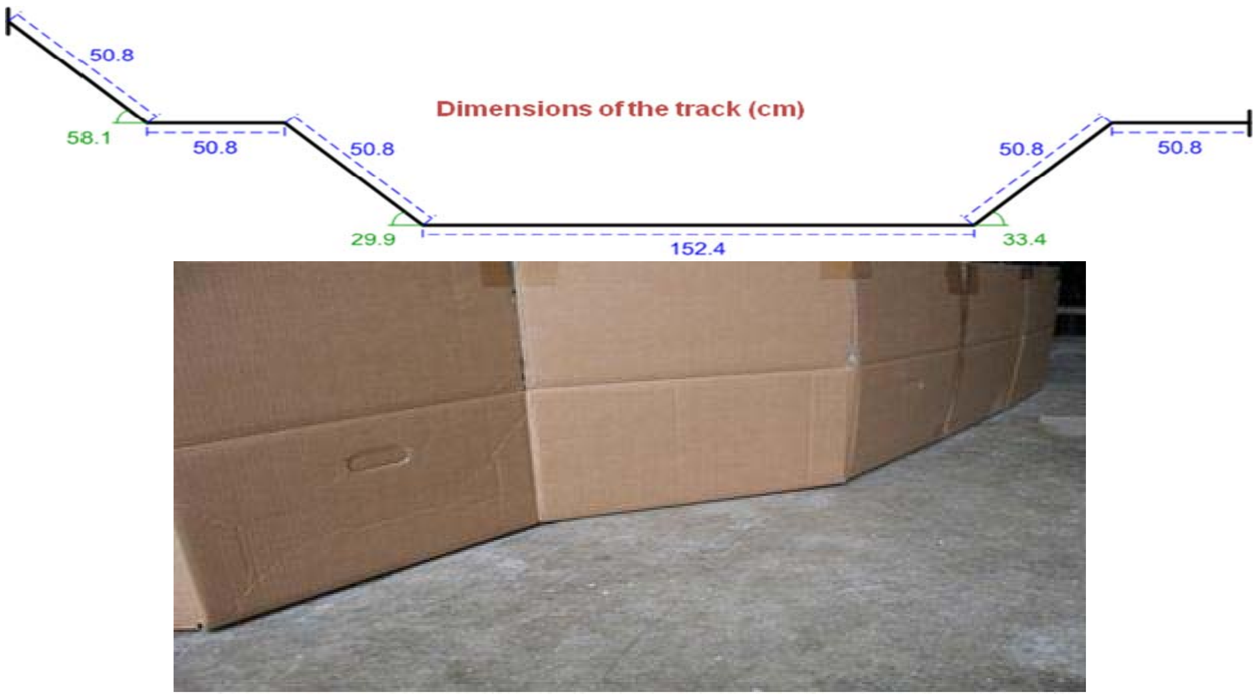



**Figure 5. Cardboard test track (Laboratory Conditions)**

## *Field testing*

A frame was made to mount the sensor setup on a tractor. The two infrared sensors were fitted on a rectangular steel bar and were separated by a distance of 30.48 cm. (12 in) .The frame can be seen in figure 6 which was mounted in the front of the tractor. The sensors can be operated at different heights above the ground. Wheat crop was used to test the sensors for determining the guidance parameters. The test track for the wheat rows can be seen in figure 7.

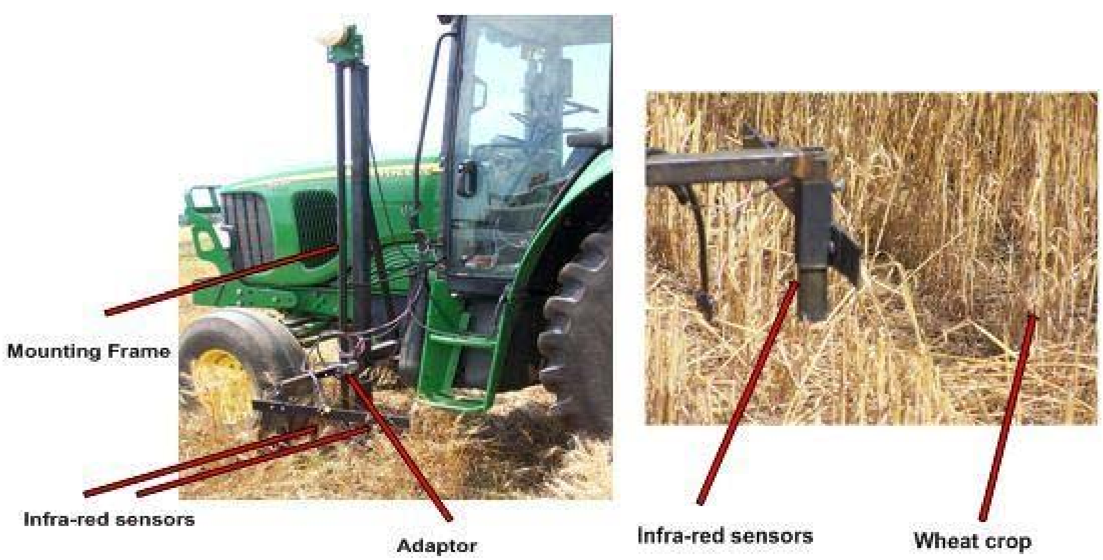
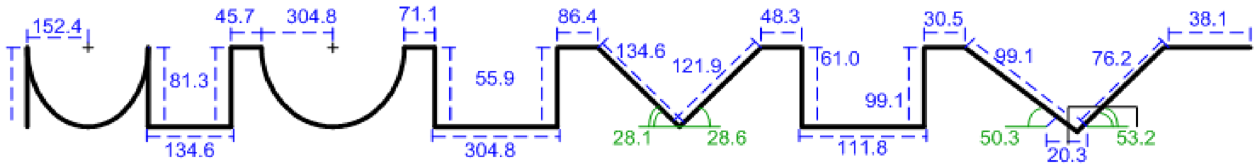



**Figure 6.Sensor configuration (field setup)**




**Shape and dimensions of the test track (cm)**


**Figure 7.Field test track (Wheat crop edge)**

## Results and Discussion

### *Lab test results*

The distance output given by IRF ($d_f$) and IRR ($d_r$) when sensing the cardboard track can be seen in figure 8. The raw distance output given by sensor 1 and sensor 2 can be seen in red and yellow respectively. Moving average with a window size of 500 was done on the raw distance output from the sensors to smooth the data. The plot clearly reveals that the sensor was able to detect the edges of the track. There was a small depression on the cardboard surface which was detected and can be seen as small peaks in the distance output plot of the sensors in figure 8.

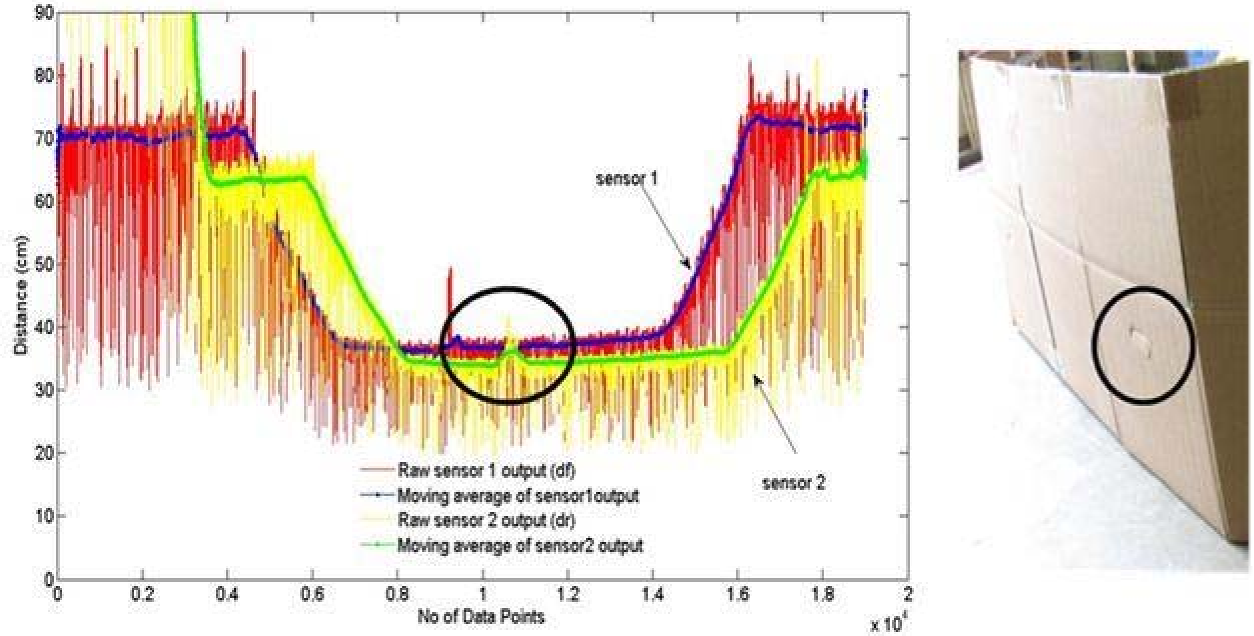



**Figure 8 Comparison of distance output given by sensor 1 (IRF) and sensor 2 (IRR) in lab conditions**

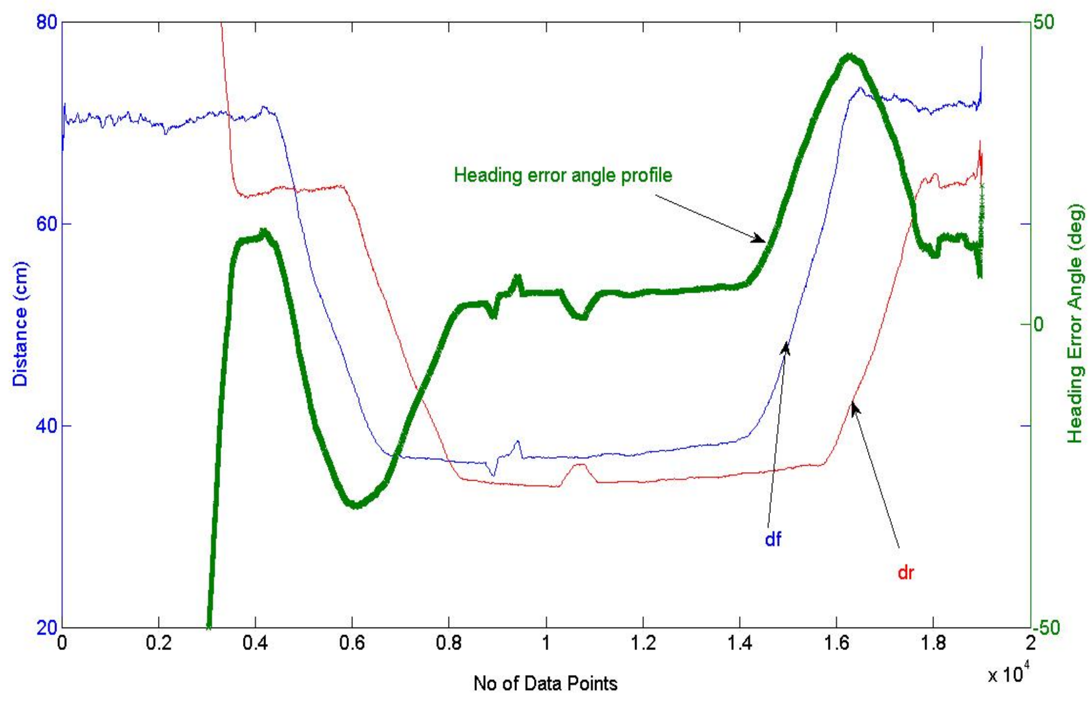



**Figure 9 Distance output and Heading error angle plot**

Figure 9 gives the heading error angle plot calculated using equation 1. The heading error angle was closer to zero degrees in the mid section of the plot which can be attributed to the flat section of the cardboard track. Sensor I and Sensor II didn't give the same output when sensing the flat straight edge of the cardboard. Sensor I had an error of 6% (figure 10) in measuring the distance which caused an error in the measurement of heading error angle. From the sensor output $d_f \neq d_r$ during straight line motion which is not true when both sensors are sensing a flat edge. Thus it was suspected that sensor I should be recalibrated.

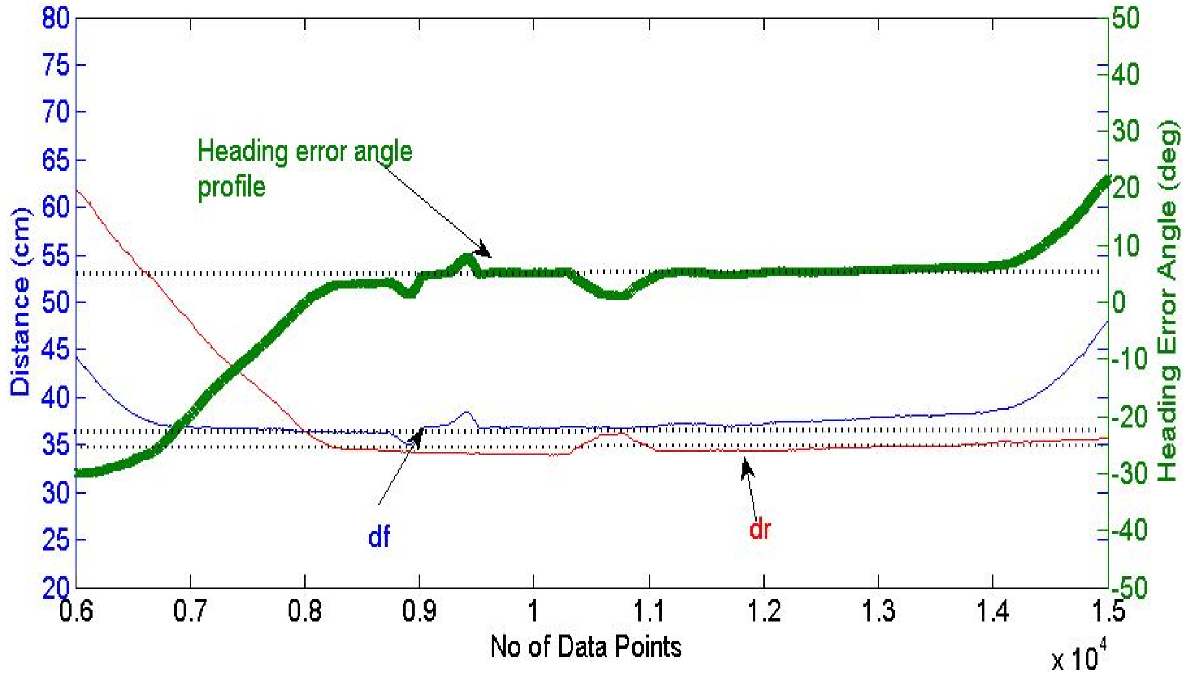



**Figure 10. Sensor Output – Linear Feature**

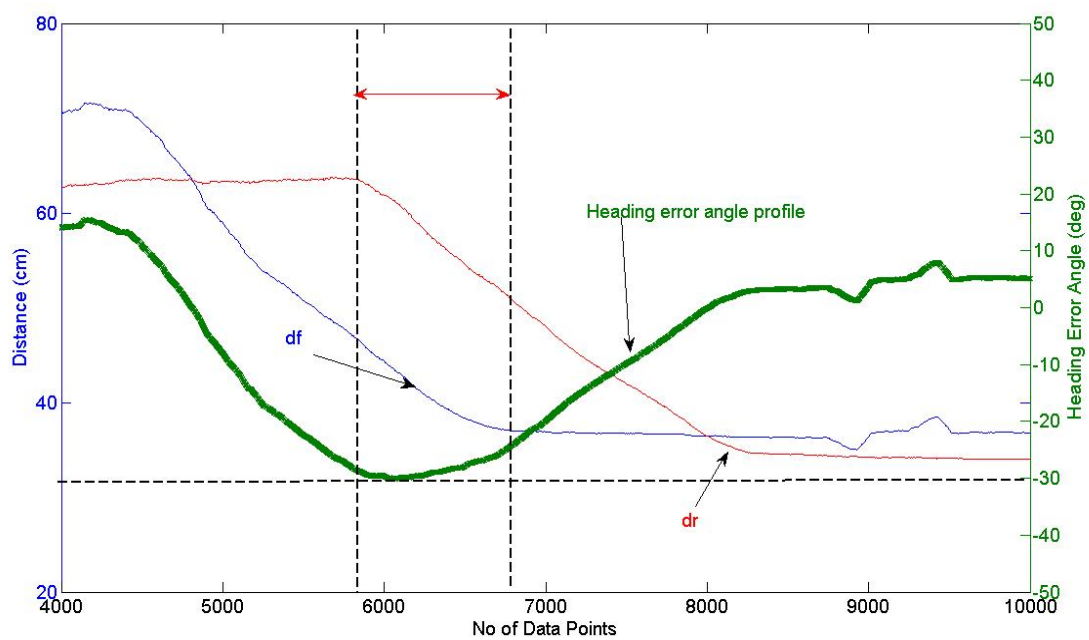



**Figure 11. Calculated Directrix – Angled surface to the left**

The end sections of the plot revealed non-zero angles with different signs because of the two non parallel edges of the test track. Figure 11 gives the response of the sensors to the left end section of the cardboard track where the heading error angle (Ø) is negative as $d_f < d_r$. Similarly figure 12 depicts the right end section of the track where the heading error angle (Ø) is positive as $d_f > d_r$. An error of 6.6% was estimated in measuring the heading error angle of left angled surface and an error of 13% was obtained in measuring the heading error angle of right angled surface of the track. These errors again can be attributed to the calibration errors of sensor I

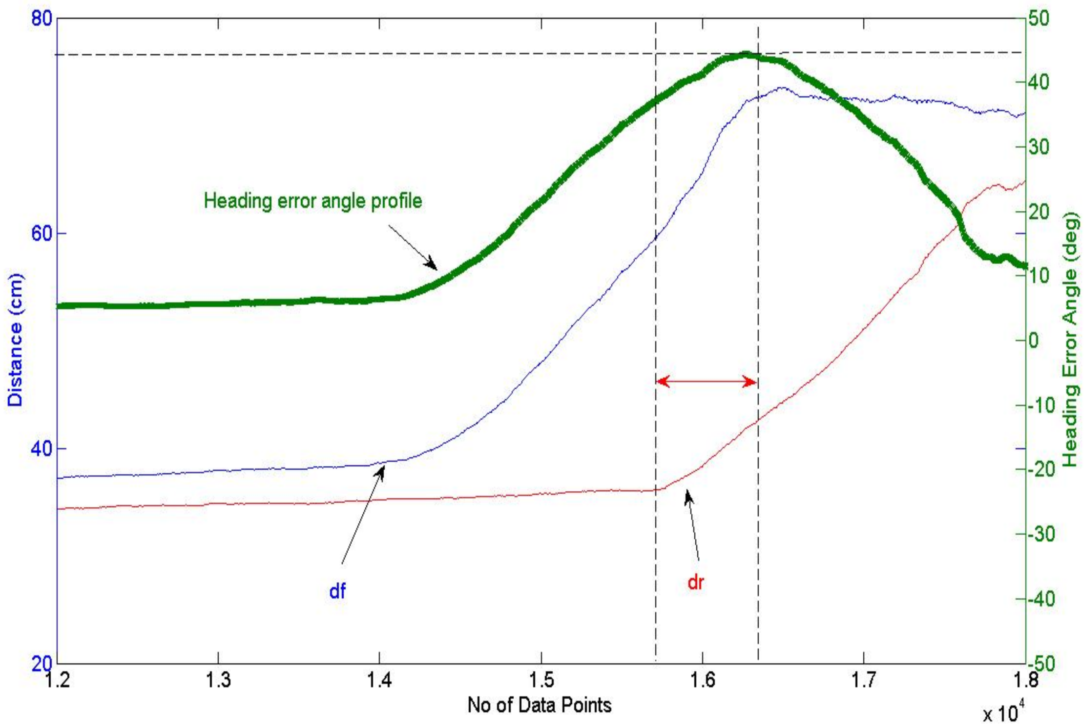



**Figure 12. Calculated Directrix – Angled surface to the Right**

Thus, the results obtained in the laboratory were satisfactory and the sensor was able to detect the profile of the cardboard test track. The sensors were then tested in the field and the results are as follows.

***Field Test Results***

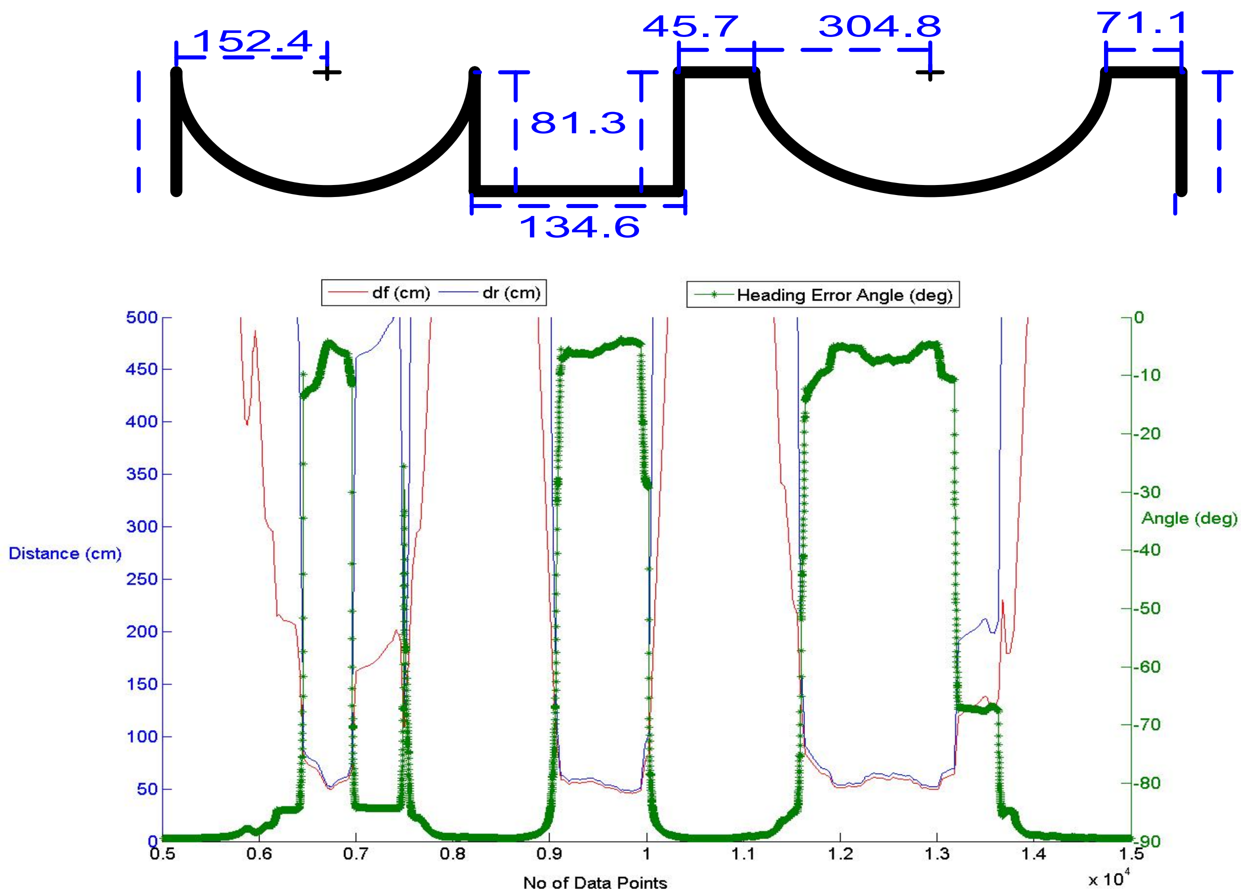



**Figure 13. Calculated Directrix – Segment I Crop Edge**

The wheat crop track was divided into segment I and segment II for comparison purposes. Segment I consisted of two arcs with arc radius 152 cm (5 ft) and 304 cm (10 ft) with some flat edges. The actual crop track (top) and the sensor response (bottom) can be seen in figure 13. $d_f$, $d_r$ and heading error angle (Ø) are plotted in red, blue and green respectively. Moving average with a window size of 500 was done to smooth the noisy data. The sensor did mimic the actual wheat crop track. The dense data in green close to the $0^0$ can be attributed to the flat edges in between the arcs and the data close to $-90^0$ is because of the very high distance output of sensors caused by the absence of crop (distances out of sensor range). In this case the tangent of their difference ($d_f$-$d_r$) would be very high. It was observed that all the angles obtained where negative in magnitude. Upon investigation, it was revealed that distance output (plot in blue) given by sensor 2 ($d_r$) was always higher than the distance output given by sensor 1. This caused the numerator of equation 1 to be always negative which resulted in negative angles. Sensor 2 seemed to behave well under 200 cm distances, but beyond 200 cm the distances were amplified which resulted in high magnitude of angles. The sensor arrangement was able to detect the segment II and can be seen in figure 14.

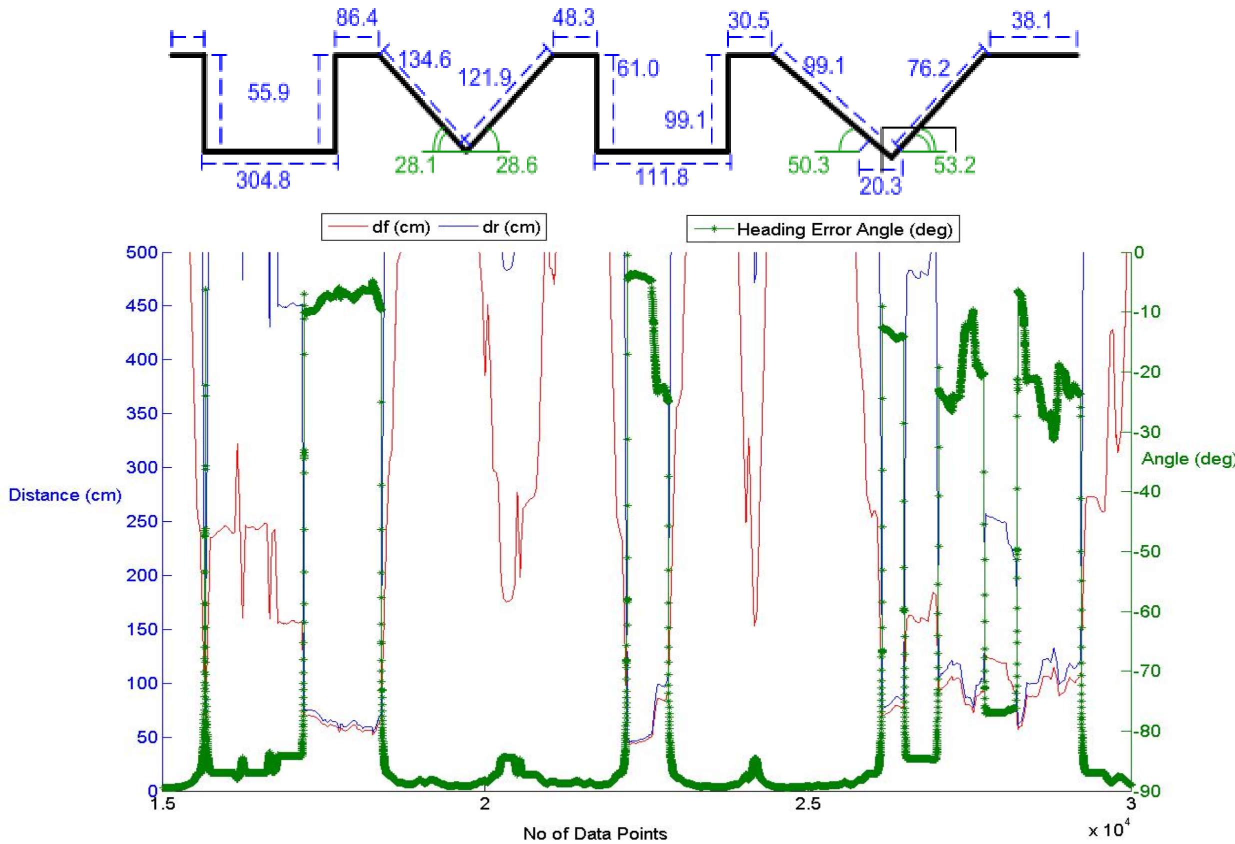



**Figure 14. Calculated Directrix – Segment II Crop Edge**

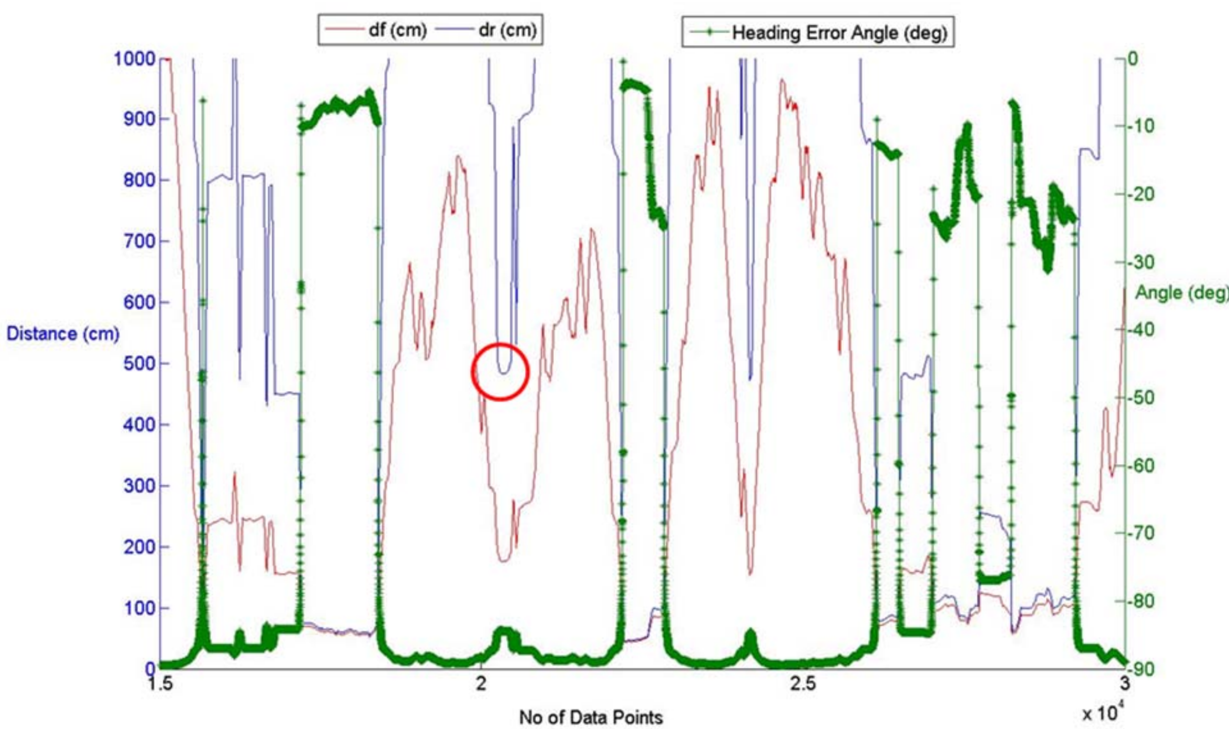



**Figure 15. Directrix Errors – Segment II crop edge**

Figure 15 reveals that the reason for obtaining high calculated heading error angles (Ø). The higher distance output ($d_r$) magnitude given by sensor 2 of more than 200 cm caused the difference ($d_f$-$d_r$) to be very high that resulted in high heading angles. From the plot it can be observed that sensor 2 outputted the same profile as sensor 1 and the outputs were almost equal in magnitude below 200 cm and above 200 cm the profile was same but the magnitudes were different. Calibration errors of sensor 2 can be the reason for drifting of distance output of sensor 2.

## Conclusions

The infra-red sensors performed well in detecting the solid target and the wheat crop edge. Further investigations have to be performed to improve the accuracy of the sensors in detecting the crop edge. These sensors can be used in combination with low-cost GPS units to obtain desired heading information required for automated guidance.

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